Vicencio, F., & Alexander, N. A. (2019). Authors' Reply to Discussion on: A parametric study on the effect of rotational ground motions on building structural responses by F Vicencio and N,A,Alexander (Soil Dyn. Earthq. Eng 2019;118:191-206). *Soil Dynamics and Earthquake Engineering*, [105592]. https://doi.org/10.1016/j.soildyn.2019.03.006

Authors' Reply to Discussion on: A parametric study on the effect of rotational ground motions on building structural responses by F Vicencio and N,A,Alexander (Soil Dyn. Earthq. Eng 2019;118:191-206)

Felipe Vicencio [a], Nicholas A. Alexander [b,1].
[a] *Researcher, Department of Civil Engineering, University of Bristol, Queen's Building, Bristol, UK*
[b] *Reader in Structural Dynamics, Department of Civil Engineering, University of Bristol, Queen's Building, Bristol, UK*

The authors would like to thank the discussers for their interest in the above paper [1]. The discussers' [2] main critique was focused on the 5Hz high-cut filter we imposed on the estimated rotational (pitch/roll) acceleration timeseries we obtained from vertical recorded accelerations at the SMART-1 array [3]. It is worth stating, that no reasonable scientist would purposefully remove certain frequency components from a timeseries without credible arguments that suggest that these components were more likely noise than signal. In addition to this, a reasonable scientist would also have to have strong arguments to suggest that these neglected/removed components are not significant to the utility of the timeseries in further analyses. This is, in fact, the case in our paper [1].

For the sake of clarity, we recapitulate the following arguments. (i) The vertical ground acceleration wavefield is spatially sampled at discrete stations (in the inner SMART-1 ring) at approximately 100m apart. (ii) This spatial sampling (that cannot be changed *a posteriori*) imposes a Nyquist frequency of approximately $f_{nyq} = V/L$ (where V is the apparent site traveling wave speed and L is the distance between stations). In the case of the SMART-1 inner array $f_{nyq} \approx$ 5Hz for the estimated rotational (pitch/roll) accelerations. (iii) We describe mathematically, in Appendix B in [1], the increasing mean interpolation/differentiation error with frequency for the rotational (pitch/roll) accelerations. (iv) As an example, Figure 4 in [1] displays the original (unfiltered) and filtered estimates for the rotational (pitch/roll) ground accelerations at a particular spatial location in the inner array. Note that the power above 5Hz is significant. However, the argumentation in Appendix B makes it clear that these components (in this case of spatial interpolation/differentiation) are noise rather than signal. Therefore, we chose to remove this spurious noise. (v) However, this question remains: are there any rotational component above 5Hz at the SMART-1 array? The answer is likely yes given the data from ARGONET Kefalonia [4]. However, it is unfortunately impossible to recover these higher frequency components when using interpolation/differentiation of the vertical ground accelerations based on spatial sampling at 100m due to the Nyquist-Shannon sampling theorem. (vi) Finally, the fundamental SSI frequencies of the low/medium rise buildings explored in our paper [1] were generally well below 5Hz. We hypothesized that the rotational components above 5Hz produced little to no effect on the response of our structural systems. Analyses with unfiltered and filtered estimates of the rotational ground motions produced no significant differences in the structural responses. This result represents a statistically significant validation of our hypothesis. This hypothesis is further strengthened by the following

[1] Corresponding Author, email: nick.alexander@bristol.ac.uk

theoretical considerations. The natural frequencies of a uniform shear building (on a rigid-base, no soil structure interaction) is displayed in figure 1. It has been calibrated so that it's first modal frequency matches the EC8 [5] empirical result.

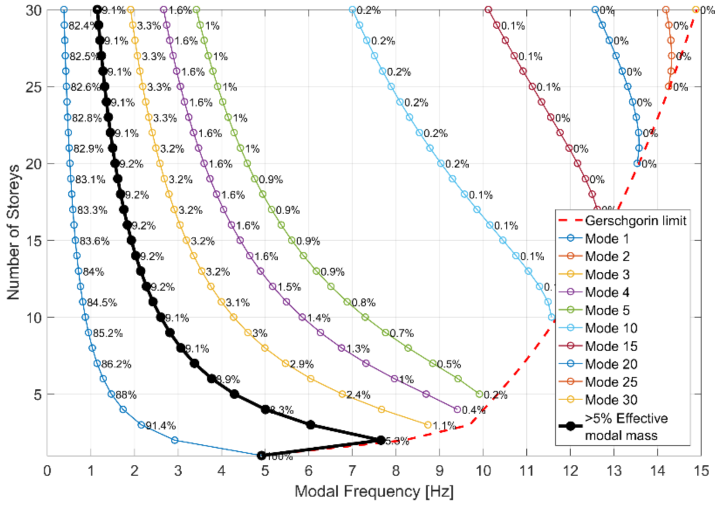

Figure 1, Shear building (fixed-based) modal frequencies vs the number of storeys. Effective modal mass displayed as % for each mode.

Figure 1 plots the modal frequencies for (steel framed) shear buildings who's first modal frequency matches equation (3). For shear buildings up to 30 storeys the modal frequencies range is approximately from 0.4Hz to 15Hz. While there are many modes above 5Hz, almost all of these modes have an effective modal mass of much less than 5%. EC8 proposes that those modes with an effective modal mass less than 5% of the total building mass can be neglected. Thus, for this uniform, regular, building system, all modes other than modes 1 and 2 can be neglected. This reduces the important frequency range to approximately from 0.4Hz to 8Hz. Note that the 2nd mode (for a 2-storey case) at 8Hz has only a 5.3% contribution so is only marginally significant. Additionally, note that the flexible base frequency is, in our study [1], 90% of the rigid base frequency (which is in keeping with Stewart et al, [6]) and this further reduces the frequency range of interest. We could also argue that the introduction of building inelasticity would further reduce these predominant resonant frequencies.

As a final piece of evidence, we have reproduced Figure 12 from [1] below (Figure 2) that uses a translational and rotational record pair (East-West component) from ARGONET Kefalonia [4] database (Event 20141108_231542 according to the National Observatory of Athens occurred on 08 November 2014 with a local magnitude of 5.0) and our system of equations (13) in [1]. While Figure 2 shows some small differences, one would conclude that the effect of the frequency content of the rotational accelerations (above 5Hz) on the response of medium/low-rise buildings is not at all significant.

In conclusion, rotational ground accelerations can be extracted from closely spaced stations (ideally spaced at $L \ll V/10$ apart where V is the site apparent traveling wave speed). This can be done for historical events and we demonstrate that this is a perfectly reasonable approach for buildings in general. Having said this, the direct recorded rotational components, as in ARGONET Kefalonia [4] database, that make use of 6-axis strong motion instruments are still to be favoured, with one caveat. This caveat is that of data paucity. We do not have many historical 6-axis records, in many different locations and with many different magnitudes. Therefore, while 6-axis instrument should be used more in future, there is likely to be much efficacy in fully utilising the historical strong motion translation databases for recovering estimates of rotational ground accelerations.

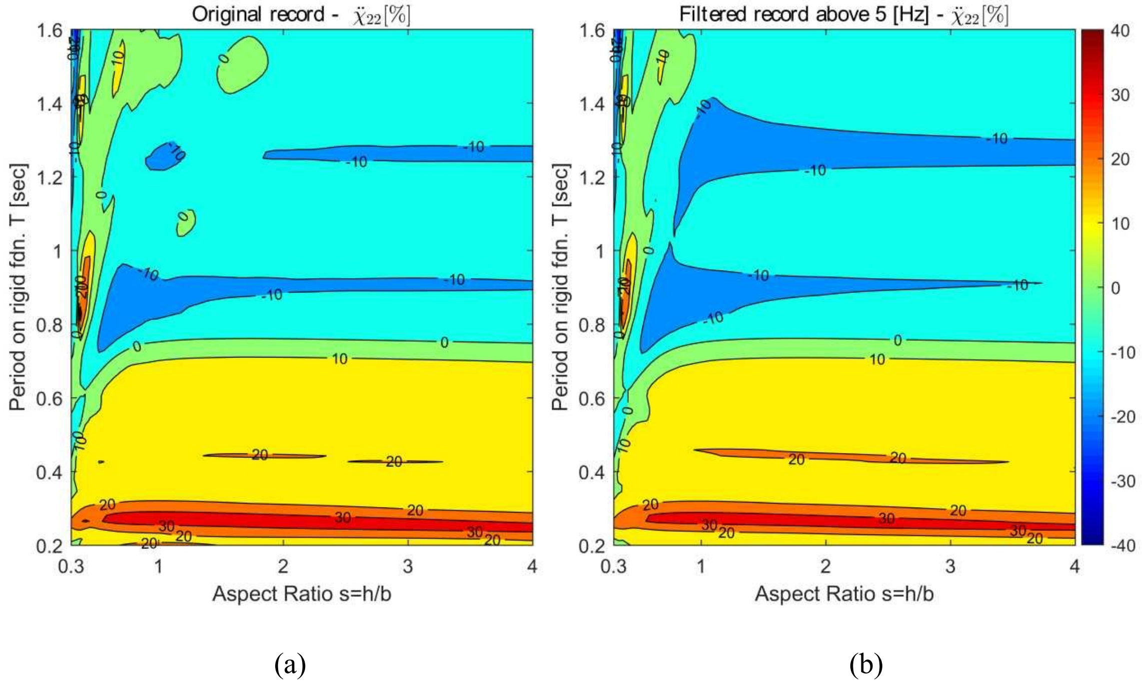

Figure 2, Change in building response acceleration due to including rotational ground acceleration (a) using original ARGONET Kefalonia records (b) using ARGONET Kefalonia rotational record filtered high-cut filtered at 5Hz.

References

[1] Vicencio, F., and N. A. Alexander (2019). "A parametric study on the effect of rotational ground motions on building structural responses." Soil Dynamics and Earthquake Engineering 118: 191-206.

[2] Bonkowski P.A. and Z. Zembat (2019), Discussion on "A parametric study on the effect of rotational ground motions on building structural responses" by F. Vicencio and N.A. Alexander (Soil Dyn Earthq Eng 2019;118:191–206), Soil Dynamics and Earthquake Engineering

[3] Institute of Earth Science, SMART-1 Array data repository, Tawain, 1980–1991. http://www.earth.sinica.edu.tw/~smdmc/.

[4] Vincent Perron, Fabrice Hollender, Armand Mariscal, Nikolaos Theodoulidis, Chrisostomos Andreou, Pierre-Yves Bard, Cécile Cornou, Régis Cottereau, Edward Marc Cushing, Alberto Frau, Sébastien Hok, Agisilaos Konidaris, Philippe Langlaude, Aurore Laurendeau, Alexandros Savvaidis, Angkeara Svay; Accelerometer, Velocimeter Dense-Array, and Rotation Sensor Datasets from the Sinaps@ Postseismic Survey (Cephalonia 2014–2015 Aftershock Sequence). Seismological Research Letters; 89 (2A): 678–687. doi: 10.1785/0220170125

[5] EC8 (2004). British Standards Institution: Eurocode 8: Design provisions for earthquake resistance of structures: Part 1-1, General rules - seismic actions and general requirements for structures. BS EN: 1998-1-1: 2004. London: British Standards Institution.

[6] Stewart J, P., R.B. Seed and L. G. Fenves (1999). "Seismic Soil-Structure Interaction in Buildings. II: Empirical Findings." Journal of Geotechnical and Geoenvironmental Engineering 125(1): 38-48.